AMMONIA-FREE NOx CONTROL SYSTEM

QUARTERLY TECHNICAL PROGRESS REPORT NO. 41865R8
JULY 1 THROUGH SEPTEMBER 30, 2005

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Disclaimers

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Abstract

Research is being conducted under United States Department of Energy (DOE) Contract DE-FC26-03NT41865 to develop a new technology to achieve very low levels of NOx emissions from pulverized coal fired boiler systems by employing a novel system level integration between the PC combustion process and the catalytic NOx reduction with CO present in the combustion flue gas. The combustor design and operating conditions will be optimized to achieve atypical flue gas conditions. This approach will not only suppress NOx generation during combustion but also further reduce NOx over a downstream catalytic reactor that does not require addition of an external reductant, such as ammonia.

This report describes the work performed during the July 1 to September 30, 2005 time period.

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1.0 EXECUTIVE SUMMARY

1.1 Project Overview

State-of-the-art NOx control technology for pulverized coal (PC) steam plants involves a combination of low NOx combustion and selective catalytic reduction (SCR) technologies. Development of these systems has approached a plateau and further improvements will likely be incremental. To advance NOx control technology to the next level, new concepts must be considered.

The objective of this project is to evaluate the viability of a novel integration between the PC combustion process and flue gas NOx reduction. The concept exploits the relationship between CO and NOx both in the combustion and flue gas NOx destruction processes to achieve very low levels of NOx from the boiler system without adding any external reductant, such as ammonia, typically used for SCR processes.

The project starts with a review and evaluation of commercial and developmental catalysts for NOx reduction and CO oxidation, including those catalysts formulations successfully used in the automotive applications, for their use in PC power plants. This knowledge, combined with prior catalyst research experience for power plant applications allows the project team to identify and test catalyst formulations robust enough for the oxidizing flue gas environment in power plants, and capable of achieving competitive NOx reduction performance and economic targets.

A detailed PC combustion study, applying computational fluid dynamics simulation program to perform boiler and burner design modeling, complements the catalyst development effort by investigating ways to optimize the combustion process for the lowest NOx formation while generating sufficient levels of CO needed by the downstream catalytic NOx reduction process. Furnace configuration, air staging, and burner design are evaluated in this process.

The study will then focus on the comparative evaluation of a conceptual, 400 MWe, coal-fired PC boiler system, utilizing this novel NOx control concept. For this evaluation, the concept plant will be compared to a traditional PC boiler configured with current low NOx combustion technology and an ammonia-based SCR system. The comparison will involve conceptual level design of the catalytic reduction system (an ammonia-free selective catalytic reactor, or AF-SCR) to obtain equipment pricing, operational costs, performance data as well as qualitative reliability information.

1.2 Progress During the Quarter

The project work during this quarter was primarily on Task 5 - Comparative Evaluation.

During the previous quarter, a 400 MWe size AF-SCR reactor was designed, which formed the basis for cost evaluation and comparison of the ammonia-free NOx control system with AF-SCR and the conventional system with ammonia-based SCR.

2.0 EXPERIMENTAL

No experimental work was performed during this quarter.

3.0 RESULTS AND DISCUSSIONS

As the previously reported work on Task 3 - Furnace Optimization indicates, adequate CO/NO ratios, as required by the downstream AF-SCR reactor, can be obtained by modifying furnace operating conditions, without significant physical changes to the burner and boiler equipment. Therefore, the design and cost impact on the furnace / boiler proper due to the new NOx control system will be minimal, and the cost evaluation effort is mainly devoted to the post combustion control by AF-SCR.

3.1 Basis for Cost Analysis

The basis for cost evaluation is the commercial-scale design of an ammonia-free selective catalytic reactor (AF-SCR) retrofitted to an existing 400 MWe bituminous coal-fired power plant, as described in the previous quarterly report. The plant is assumed to have existing low NOx burners and to add the AF-SCR system to further reduces NOx. The assumed site conditions are an elevation 425 feet above sea level, design ambient temperature of 60ºF, and relative humidity of 60%. The reactor is designed to produce an 80% NOx reduction (outlet NOx = 0.08 lb/MMBtu).

The catalyst used is activated alumina (AA) based, honeycomb type, with iron oxide and copper oxide as active components. The selected honeycomb configuration is one that is typical for conventional SCR catalysts, with 7.1 mm pitch, 0.7 mm wall thickness, and 1 m monolith length. The honeycomb will be prepared by mixing powders of substrate material, active species and binder material into a homogeneous paste and extruding the paste into monolith form.

3.2 Cost of Catalyst

Cost of catalyst contains the cost of raw materials (including substrate and active components) and cost of manufacturing. It is assumed that the same manufacturing process used today for honeycomb type SCR catalyst will be used for AF-SCR catalyst. Therefore the cost of the AF-SCR catalyst may be estimated based on the typical cost of conventional SCR catalysts and costs of raw materials. As shown in Table 1, the bulk costs for AF-SCR raw materials (activated Al_2O_3, CuO and Fe_2O_3) are significantly lower than those for SCR raw materials. Therefore, the AF-SCR catalysts cost is estimated to be about $90 per cubic foot, which is 29% less than that of conventional SCR catalyst.

Table 1. Estimation of AF-SCR Catalyst Cost

SCR Catalyst Cost Calculation		
SCR Catalyst Delivered Cost	\$/m3	4500
	\$/ft3	127
	\$/lb	6.57
Catalyst Real Density	lb/ft3	19.4
SCR Bulk Raw Material Cost		
V2O5 Bulk Cost	\$/lb	3.90
WO3 Bulk Cost	\$/lb	4.12
TiO2 Bulk Cost	\$/lb	2.50
Catalyst Raw Material Cost	\$/lb	2.64
Balance of Catalyst Cost	\$/lb	3.92
New Catalyst Cost Estimate		
Bulk Raw Material Cost		
CuO	\$/lb	2.98
Fe2O3	\$/lb	0.39
Activated Alumina	\$/lb	0.50
Catalyst Raw Material Cost	\$/lb	0.74
New Catalyst Cost	\$/lb	4.66
	\$/m3	3194
	\$/ft3	90.4

3.3 Cost of Ammonia

Conventional SCR systems use anhydrous or aqueous ammonia, or urea as reagent. Of the three, anhydrous ammonia is the most concentrated and least expensive reagent, and requires least on-site processing. Anhydrous ammonia is selected as the reagent for this cost evaluation.

Natural gas is used in the manufacturing of ammonia and accounts for as much as 90% of the product cost of anhydrous ammonia. Since 2002, the natural gas price has risen sharply from under \$3/MMBtu to over \$10/MMBtu. Figure 1 shows the trend of anhydrous ammonia price (CFR at Tampa, Florida, and FOB at Yuzhnyy, Ukraine) over the same period (http://www.fertilizerworks.com/html/market/TheMarket.pdf.). A price of \$350/ton for anhydrous ammonia delivered to the plant is used in this study.

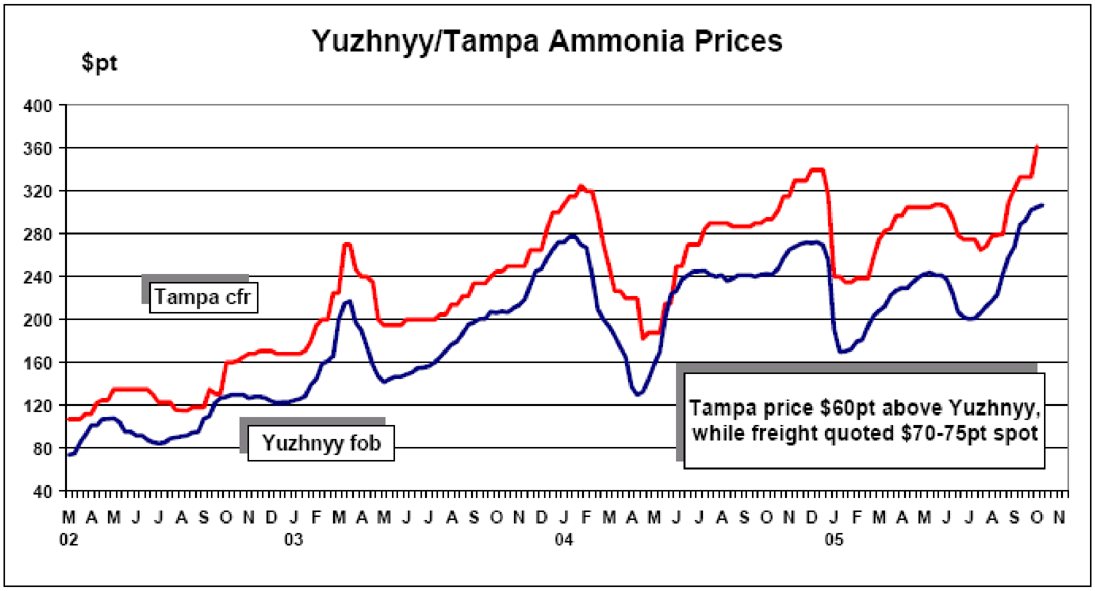

Figure 1. Price Trend of Anhydrous Ammonia

3.4 Cost Evaluation of Ammonia-Free NOx Reduction System

Table 2 summarizes the overall performance data and cost summary of the AF-SCR and conventional SCR systems for the 400 MWe pulverized coal fired plant described in 3.1. The AF-SCR has lower capital cost than SCR due to the elimination of the ammonia storage and handling system, and also the low cost catalyst used for AF-SCR. The estimated capital cost for the AF-SCR system is $81/kw, 17% lower than a SCR system which is estimated at $98/kw. For the 400 MWe plant, the savings in capital investment due to AF-SCR is approximately 6.8 million dollars.

The largest O&M cost saving is the avoided cost of ammonia reagent. Smaller savings are projected in catalyst replacement cost, fixed O&M cost and system energy cost. For the 400 MWe plant, the total O&M cost of the AF-SCR system is about 0.89 million dollars per year.

Table 2 gives the levelized cost analysis of NOx removal, in both constant 2004 dollars and current dollars. The cost of NOx removal by AF-SCR system is estimated as $776/ ton, or 29.5% lower than the removal cost with current SCR technology. For the 400MWe unit, the present value of total cost savings for NOx control due to the AF-SCR system is approximately 19 million dollars.

It should be noted that the cost analysis described here is based on anhydrous ammonia, which is the least expensive ammonia reagent. Anhydrous ammonia is a controlled hazardous substance and is generally not acceptable for plants located in or near cities. Additionally, the analysis includes only direct costs, without considering the costs associated with the special siting, permitting, and safety training requirements for an anhydrous ammonia system.

Table 2. NOx Control Performance and Cost Summary

Item	Unit	SCR	AF SCR
A. Plant Overall Data			
Plant Net Electrical Output	MWe	400	400
Total Plant Heat Input	MMBtu/hr	3567	3567
SCR Inlet NOx	lb/MMBtu	0.40	0.40
SCR NOx Reduction	%	80.0%	80.0%
Plant NOx Emissions	lb/MMBtu	0.08	0.08
Total Flue Gas Flow	lb/hr	3,500,500	3,500,500
NH3 Consumption (anhydrous)	lb/hr	466	0
Atomizing Air Consumption	lb/hr	9320	0
Total Catalyst Volume	M^3	371	371
Catalyst Life	hours	24,000	24,000
SCR Pressure Drop	"H2O	4.0	4.0
Fan Efficiency	%	70%	70%
Anhydrous Ammonia Cost	$/ton	350	-
Electricity Cost for Plant Use	$/kWhr	0.04	0.04
Plant Annual Capacity Factor	%	85%	85%
Total NOx Removed	ton/yr	4,250	4,250
B. Capital Cost			
Ammonia System Design & Supply	$	2,900,000	-
Initial Catalyst Charge	$	1,669,500	1,184,902
Reactor and BOP Modification D. & S.	$	14,950,217	14,950,217
Total System Erection & Commissioning	$	19,519,717	16,135,120
Total DeNOx Retrofit Capital Cost	$/kW	98	81
	$	39,039,434	32,270,239
Savings in Capital Cost	$		6,769,195
	%		17.3%
C. Operating and Maintenance Cost			
Fixed O&M Cost	$/yr	257,660	212,984
	$/kW-yr	0.644	0.532
Anhydrous Ammonia Cost	$/yr	607,221	-
	mills/kWhr	0.204	-
Catalyst Replacement Cost	$/yr	710,227	504,073
	mills/kWhr	0.238	0.169
Energy Requirement			
Ammonia Heating	$/yr	23,965	-
Atomizing Air	$/yr	3,294	-
Reactor Pressure Loss	$/yr	234,741	234,741
Total Energy Cost	$/yr	261,999	234,741
	mills/kWhr	0.088	0.079
Total Variable O&M Cost	$/yr	1,579,447	738,814
	mills/kWhr	0.530	0.248

Table 3. Financial Analysis for NOx Control

Item	Unit	SCR	AF SCR
D. Financial Parameters			
Term	year	30	30
Inflation Rate	%	3.0%	3.0%
Real Escalation	%	0.0%	0.0%
Constant Dollar Cost of Capital	%	6.0%	6.0%
Apparent Escalation	%	3.0%	3.0%
Discount Rate	%	9.2%	9.2%
E. Levelized Cost, Current $			
Levelization Factor for Capital Cost		0.099	0.099
Levelization Factor for O&M Cost		1.361	1.361
Capital Cost	$/yr	3,860,756	3,191,325
	mills/kWhr	1.296	1.071
Fixed O&M Cost	$/yr	350,742	289,925
	mills/kWhr	0.118	0.097
Variable O&M Cost	$/yr	2,150,032	1,005,714
	mills/kWhr	0.722	0.338
Total Levelized NOx Control Cost	$/yr	6,361,530	4,486,965
	mills/kWhr	2.136	1.507
	$/ton NOx	1,497	1,056
Cost Saving	%		29.5%
	$/yr		1,874,565
PV of Total Savings	$		18,955,343
F. Levelized Cost in 2004 $			
Levelization Factor for Capital Cost		0.073	0.073
Levelization Factor for O&M Cost		1.000	1.000
Capital Cost	$/yr	2,836,172	2,344,398
	mills/kWhr	0.952	0.787
Fixed O&M Cost	$/yr	257,660	212,984
	mills/kWhr	0.087	0.072
Variable O&M Cost	$/yr	1,579,447	738,814
	mills/kWhr	0.530	0.248
Total Levelized NOx Control Cost	$/yr	4,673,280	3,296,195
	mills/kWhr	1.569	1.107
	$/ton NOx	1,100	776
Cost Saving	%	-	29.5%
	$/yr	-	1,377,085
PV of Total Savings	$	-	**$ 18,955,343**

4.0 CONCLUSION

Based on the conceptual design and predicted performance data of the ammonia-free selective catalytic reactor (AF-SCR) for a 400 MWe size coal-fired power plant, economic evaluation has been performed for NOx reduction with the AF-SCR system. By eliminating ammonia as reagent and using of low cost catalyst, the AF-SCR system will have significant cost advantages. Compared to the state-of-the-art SCR system, the AF-SCR system is projected to be 17% lower in capital investment, and almost 30% lower in cost of per ton NOx removed.